DOE/MC/30056 -- 5771

Utilization of Lightweight Materials Made From Coal Gasification Slags

Quarterly Report
March 1 - May 30, 1997

Work Performed Under Contract No.: DE-FC21-94MC30056

For
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1.0 PROJECT OBJECTIVES, SCOPE AND DESCRIPTION OF TASKS

1.1 Introduction

The integrated-gasification combined-cycle (IGCC) process is an emerging technology that utilizes coal for power generation and production of chemical feedstocks. However, the process generates large amounts of solid waste, consisting of vitrified ash (slag) and some unconverted carbon. In previous projects, Praxis investigated the utilization of "as-generated" slags for a wide variety of applications in road construction, cement and concrete production, agricultural applications, and as a landfill material. From these studies, we found that it would be extremely difficult for "as-generated" slag to find large-scale acceptance in the marketplace even at no cost because the materials it could replace were abundantly available at very low cost. It was further determined that the unconverted carbon, or char, in the slag is detrimental to its utilization as sand or fine aggregate. It became apparent that a more promising approach would be to develop a variety of value-added products from slag that meet specific industry requirements. This approach was made feasible by the discovery that slag undergoes expansion and forms a lightweight material when subjected to controlled heating in a kiln at temperatures between 1400 and 1700°F. These results confirmed the potential for using expanded slag as a substitute for conventional lightweight aggregates (LWA). The technology to produce lightweight and ultra-lightweight aggregates (ULWA) from slag was subsequently developed by Praxis with funding from the Electric Power Research Institute (EPRI), Illinois Clean Coal Institute (ICCI), and internal resources.

The major objectives of the subject project are to demonstrate the technical and economic viability of commercial production of LWA and ULWA from slag and to test the suitability of these aggregates for various applications. The project goals are to be accomplished in two phases: Phase I, comprising the production of LWA and ULWA from slag at the large pilot scale, and Phase II, which involves commercial evaluation of these aggregates in a number of applications.

Primary funding for the project is provided by DOE's Morgantown Energy Technology center (METC) with significant cost sharing by Electric Power Research Institute (EPRI) and Illinois Clean Coal Institute (ICCI).

1.2 Scope of Work

The Phase I scope consisted of collecting a 20-ton sample of slag (primary slag), processing it for char removal, and pyroprocessing it to produce expanded slag aggregates of various size gradations and unit weights, ranging from 12 to 50 lb/ft^3. In Phase II, the expanded slag aggregates will be tested for their suitability in manufacturing precast concrete products (e.g., masonry blocks and roof tiles) and insulating concrete, first at the laboratory scale and subsequently in commercial manufacturing plants. These products will be evaluated using ASTM and industry test methods. Technical data generated during production and testing of the products will be used to assess the overall technical viability of expanded slag production. Relevant cost data for physical and pyroprocessing of slag to produce expanded slag aggregates will be gathered for comparison with (i) the management and disposal costs for slag or similar wastes and (ii) production costs for conventional materials which the slag aggregates would replace. In addition, a market assessment will be made to evaluate the economic viability of these utilization technologies.

1.3 Phase I Task Description

A summary of the tasks performed in Phase I is given below:

Task 1.1 **Laboratory and Economic Analysis Plan Development**: Development of a detailed work plan for Phase I and an outline of the Phase II work.

Task 1.2 **Production of Lightweight Aggregates from Slag**: This task covered selection and procurement of project slag samples, slag preparation including screening and char removal, and slag expansion in a direct-fired kiln and fluid bed expander. The char recovered from the slag preparation operation was evaluated for use as a kiln fuel and gasifier feed. Environmental data for slag-based lightweight aggregate (SLA) production was collected.

Task 1.3 **Data Analysis of Slag Preparation and Expansion**: Analysis and interpretation of project data, including development of material and energy balances for slag processing and product evaluation.

Task 1.4 **Economic Analysis of Expanded Slag Production**: Economic analysis of the utilization of expanded slag was conducted by determining production costs for slag-based LWAs and ULWAs. Expanded slag production costs were compared with the market value of similar products both with and without taking into account the avoided costs of disposal and with the costs of management of slag as a solid waste.

Task 1.5 **Topical and Other Reports**: Preparation topical, financial status, and technical progress reports in accordance with the Statement of Work.

1.4 Phase II Task Description

A summary of the tasks to be performed in Phase II is given below.

Task 2.1 **Test Plan for Applications of Expanded Slags (Field Studies)**: This task involves the development of selection criteria and a field test plan for applications of expanded slag. This plan will serve as a guide in the selection and implementation of field demonstrations for the most promising expanded slag utilization applications. Field applications will be selected on the basis of laboratory results, the marketability of the products, and the suitability of the project slags for producing them. The following applications are under consideration for testing:

- Lightweight concrete blocks made from 50 lb/ft^3 SLA
- Lightweight roof tiles made from 40 lb/ft^3 SLA
- Loose fill insulation made from 16 lb/ft^3 SLA
- Lightweight insulating concrete made from 16 lb/ft^3 SLA

Task 2.2 **Field Studies to Test Expanded Slag Utilization**: Under this task, field testing of the applications identified in Phase II, Task 2.1, will begin with test work to optimize the concrete mixes made from expanded slag.

Task 2.3 **Data Analysis of Commercial Utilization of Expanded Slags:** The objective of this task is to assimilate the data and test results collected during Phase II, Task 2.2, to convert these findings to common engineering terms, and to correlate these results with comparable information for conventional lightweight aggregates as reported in the literature. The data analysis will provide specific answers to the following issues:

- Performance of expanded slag compared with that of conventional materials
- Technical viability of lightweight and ultra-lightweight slags as aggregates.

Task 2.4 **Economic Analysis of Expanded Slag Utilization:** The objective of this task is to expand upon the preliminary economic assessment of expanded slag utilization conducted during Phase I. The economics will be studied based on the production costs for SLA in comparison with current market prices for conventional materials. During the Phase I preliminary evaluation, two production scenarios emerged:

- Production of SLA at the gasifier location (on-site production)
- Production of SLA at a lightweight aggregate facility (off-site production)

The impact of the avoided costs of slag disposal on the economics of SLA production will also be evaluated. Slag utilization data and product samples will be made available to commercial lightweight aggregate users for validation of estimated market prices. The impact of SLA market prices on the economics of SLA production will also be studied.

Task 2.5 **Final Report:** The data generated and collected during the project will be compiled in a final report to be submitted at the end of the project that will be a comprehensive description of the results achieved, consistent with the Reporting Requirements. Data from topical and field reports will be summarized. The report will include the original hypothesis of the project and present the investigative approaches used, complete with problems encountered or departures from the planned methodology, and an assessment of their impact on the project results.

1.5 Scope of This Document

This is the eleventh quarterly report and summarizes the work undertaken during the performance period between 1 March 1997 and 31 May 1997. This is the fourth quarterly report for Phase II. This document summarizes the Phase II accomplishments to date along with the major accomplishments from Phase I.

2.0 SUMMARY OF WORK DONE DURING THIS REPORTING PERIOD

2.1 Summary of Major Accomplishments

The following was accomplished during the current reporting period:

1. A 2-ton sample of Slag III (from the Wabash River plant) was procured and processed for char removal. The prepared slag was shipped for pyroprocessing to produce SLA.

2. Preparatory work needed for pilot production of SLA (grinding the clay binder, drying the char-free slag, etc.) was completed.

3. Production of cement concrete waterproof panels using SLA was initiated. These panels are used in the construction industry.

4. Expanded slag is undergoing testing and evaluation for horticultural/nursery applications by a major nursery in Tennessee.

2.2 Chronological Listing of Significant Events in This Quarter

The following significant events occurred during the current reporting period:

Date	Description
4/30/97	Processing of Slag III for char removal was completed
5/20/97	Preparatory work for Slag III pyroprocessing was completed

3.0 TO DATE ACCOMPLISHMENTS

A summary of the work completed in Phase I is given below.

Date	Phase I Accomplishments Description
10/24/94	Draft Laboratory and Economic Analysis Plan (project work plan) submitted
11/18/94	Slag char removal completed on the advance sample and prepared slag laboratory expansion testing initiated
12/02/94	Final "Laboratory and Economic Analysis Plan" prepared and submitted
05/21/95	Primary slag sample (20 ton) received at Penn State for preparation
06/01/95	Pilot unit for char removal set up and processing work started
08/20/95	Primary slag sample processing for char removal completed
9/10/95	Laboratory expansion studies of slag and slag/clay blends started
10/15/95	1-ft and 3-ft diameter kilns commissioned for pilot testing
11/15/95	Pilot testing of Slag I and Slag II and pellets in 3-ft dia. direct-fired kiln completed
11/17/95	Pilot testing using fluidized bed expander completed
12/12/95	SLA product characterization initiated
1/20/96	Laboratories for testing of SLA products identified
2/16/96	Test plan for second batch of fluid bed expander testing at Fuller completed

A summary of the work completed in Phase II to date is given below.

Date	Phase II Accomplishments Description
4/30/96	Application for continuation of the project to Phase II submitted
5/31/96	Phase I Final Report (draft) submitted to METC
7/1/96	Phase I Topical Report (final version) submitted
7/14/96	Approval for continuation of the project to Phase II was received from METC
7/14/96	Structural concrete laboratory tests started
7/15/96	Lab testing of SLA for roof tile and insulating concrete applications completed
7/15/96	Evaluation of SLA for completed
7/30/96	Evaluation of SLA for loose fill insulation completed
10/10/96	Mix designs for block production selected
11/10/96	Laboratory evaluation of the Slag II completed
10/30/96	Structural concrete laboratory tests completed
11/10/96	Laboratory evaluation of Slag III for LWA production completed
1/10/97	Laboratory testing of SLA for structural concrete application completed
2/19/97	First batch of laboratory tests of selected block mixes completed
4/30/97	Processing of Slag III for char removal completed
5/20/97	Preparatory work for Slag III pyroprocessing completed

4.0 TECHNICAL PROGRESS REPORT

4.1 Manufacture and Testing of Masonry Blocks

The objective of this subtask is to use commercial-scale concrete block manufacturing equipment and techniques to produce blocks from expanded slag. This work continued from the previous quarter at the facilities of Harvey Cement Products Company, Inc., a major block manufacturer and distributor in the greater Chicago area. Harvey Cement was selected as they are located close to the recently commissioned Wabash River IGCC plant which is a potential long-term source of slag and hence slag-based LWA. A number of block mix designs were developed by Praxis based on particle size distribution and unit weight information obtained from Harvey Cement. Test mixes were formulated with the objective of manufacturing two types of blocks:

- Normal-weight blocks with a dry weight of approximately 33.5 lb
- Lightweight blocks with a dry weight of approximately 27 lb.

For both block mixes, conventional lightweight aggregate LWA (H) was replaced by slag lightweight aggregates of two types:

- Fine slag lightweight aggregate produced from a 10 x 50M slag feed (SLA F)
- Coarse slag lightweight aggregate produced from a 1/4" x 10M slag feed (SLA C).

The mix designs used for block production shown in Table 1 have been updated. The cement-to-aggregate ratio used is identical to that currently used at the plant. For the lightweight blocks, the cement-to-aggregate ratio was 1:6.6, and for regular blocks it was 1:8.7.

Water was added on an as-required basis depending on the overall workability of the aggregates and the cement paste in the mix.

Test specimens (2" x 4" cylinders) were made from the concrete and stored in a commercial block curing chamber. A total of nine blocks were made for each batch, which allowed three blocks per compression test. These tests were conducted after 3, 7, and 28 days of curing. For the last batch, only six specimens were made, which were tested after 3 and 28 days of curing.

The blocks made using fine expanded slag (SLA F) proved to have higher compressive strength than those made from the coarser expanded slag (SLA C). For example, a regular block mix using SLA F (Test 21997-1) had a 28-day compressive strength of 1639 psi, while one made using SLA C had a strength of 1519 psi (Test 21997-2). A similar trend was apparent in the case of lightweight blocks in which higher quantities of SLA were used.

The compression test results indicate that at both cement-to-aggregate ratios used, the 28-day strength was generally higher than the ASTM requirement of 1400 psi for above-grade blocks but lower than the 2000-psi requirement for below-grade load-bearing blocks. The strength of the concrete was lower than expected. We are currently looking into the size analysis of the aggregates to determine methods of improving strength. A new batch of blocks will then be made. In any event, the strength values can be increased by adding a higher proportion of cement to the mix.

Table 1. Results of Batch Mix Tests Conducted for Masonry Blocks Using SLA

	Materials Used by Volume, ml							Compressive Strength, psi		
Test Batch	LS	SS	SLA F	SLA C	Total Aggr.	Cement	Concrete Unit wt lb/ft^3	3-day	7-day	28-day
Unit wt, lb/ft^3	83.8	88.2	43.9	44.7		94.0	-	-	-	-
Regular-weight block mixes (cement-to-aggregate ratio of 1:8.7 by volume)										
21997-1	1650	630	720	-	3000	346	160.4	1090	1246	1636
21997-2	1650	630	-	720	3000	346	166.9	1285	1324	1519
Lightweight block mixes (cement-to-aggregate ratio of 1:6.6 by volume)										
21997-3	1290	-	1710	-	3000	453	126.3	1012	1168	1402
21997-4	1290	-	-	1710	3000	453	123.9	934	1012	1168
21997-5	645	-	855	0	1500	264	122.3	1051	-	1519

4.2 Laboratory Evaluation of SLA for Structural Concrete Application

The objective of this test program was to develop mix designs to produce sand and SLA-based cement concretes with compressive strengths of 2500-4000 psi at corresponding unit weights in the 115-105 lb/ft^3 range. This was accomplished by varying the proportion of cement relative to SLA. The test results were reported in the previous quarterly report. Tests conducted at the higher (6.5 $sacks/yd^3$ concrete) cement level resulted in compressive strengths of 3480 and 4380 psi for the 7- and 28-day curing periods, respectively, at a unit weight below 115 lb/ft^3. These strength values exceed the ASTM 28-day requirement. The control test strengths using clay LWA (Test 2210) were 4040 and 5100 psi which are in a comparable range. The specimens were saved in order to conduct the following tests at a later date:

- Freeze/Thaw, ASTM C 666
- Drying Shrinkage, ASTM C157
- Staining, ASTM C 641

4.3 Pilot Processing of Slag III for Char Removal

A third slag sample (Slag III) was obtained from the Wabash River Repowering Project IGCC plant. This slag was added to the project with the objectives of extending the project findings to another slag. The effort will be focused on producing SLA suitable for structural and roof tile applications with high strength. In order to achieve higher strength, the new SLA product will be generated at a higher unit weight of about 55 lb/ft^3, which is expected to result in both a stronger aggregate and stronger concrete.

Laboratory-scale expansion tests using a 5-gallon sample of Slag III generated a product with a low unit weight of 22.1 lb/ft^3 from discrete particles at a lab furnace temperature of 1600°F. These results indicate that a product with a unit weight in the 30-55 lb/ft^3 range could be produced at temperatures of <1500°F.

Based on the positive results from the laboratory tests, the decision was made to obtain a large sample of Slag III to produce SLA products for testing and evaluation. Ten 55-gallon drums of the slag was obtained and processed for char removal using the same equipment and procedures as used for processing Slag I. The char removal results are given in Table 2.

Table 2. Results of Processing Slag III for Char Removal

Size Fraction	Slag Feed		Slag Product		Char Product	
	Wt%	Ash, %	Wt%	Ash, %	Wt%	Ash, %
+6M	1.94	98.7	2.02	100.6	0.00	0.0
6 x 8M	3.41	96.1	3.75	101.1	0.29	34.0
8 x 12M	6.98	93.5	6.88	101.3	1.99	29.7
12 x 16M	13.15	86.5	12.97	101.4	6.85	29.1
16 x 20M	18.35	74.5	16.87	101.4	18.53	29.6
20 x 30M	16.37	63.6	13.39	101.5	22.78	29.0
30 x 40M	14.04	62.8	12.60	100.8	18.71	28.1
40 x 50M	10.53	68.1	11.59	100.3	11.58	27.3
50 x 70M	6.42	75.4	8.92	100.9	5.81	28.1
70 x 100M	3.20	79.6	5.53	101.7	2.53	31.9
100 x 200M	2.29	84.5	4.66	102.4	2.08	47.2
200 x 400M	0.91	78.5	0.43	101.6	1.43	67.9
-400M	2.41	76.5	0.39	100.0	7.42	72.2
Total	100.00	75.1	100.00	101.2	100.00	32.9

The yield of clean slag by drum lots for each test was documented and is reported in Table 3. The calculated yield from the ash balance for a composite sample collected from various drums was 62.7% (dry) which compares well with the yield of 62.9% calculated from the weighted average of the drum lots. The ash of the char sample analyzed at 32.9%. Based on test data for Slag I it is possible that the ash content could be further reduced, but no efforts have yet been made in this regard for Slag III.

Table 3. Char Separation Results

Lot/Batch No.	1	2	3	4	5	6	7	Total
Quantity, drums	1/2	1	1-1/2	1-1/2	1-1/2	2	2	10
Yield	62.2	56.0	66.8	60.6	66.3	63.5	61.8	62.9

4.4 Laboratory Evaluation of SLA in Nursery Applications

Expanded slag was tested as a partial substitute for vermiculite and expanded perlite in horticultural applications. It is anticipated that the higher density of expanded slag would have a favorable impact on the durability of potting mixes. This test work was done at the Evergreen Nursery located in Kingsport, TN. This nursery was selected based on their expertise in this area, the unique techniques they employ to control the supply of nutrients, and their willingness to test a new material.

The SLA used for this test work had a topsize of 1/4" and unit weight of 18.8 lb/ft^3. The size distribution of the sample is given in Table 4.

Table 4. Size Distribution of SLA Used in Horticultural Application

Size	1/2" x 1/4"	1/4" x 4M	4 x 12M	12 x 30M	30 x 50M	50 x 100M	100M x 0
Direct wt%	-	13.2	59.6	15.0	8.3	2.2	1.7
Cum. wt% Passing	100	100	86.8	27.2	12.2	3.9	1.7

Testing and evaluation involved preparation of various potting mixes measuring approximately 1 yd^3 using expanded slag as a partial or total substitute for perlite and vermiculite which are added to improve porosity and water retention. The vermiculite also makes some trace elements available to the plant.

Three potting mix batches were formulated consisting of (1) a control sample without expanded slag, (2) a sample where the expanded slag partially replaced the perlite and vermiculite, and (3) a sample in which the slag completely replaced these materials. Each batch also contained 4 lb fertilizer (14/14/14) and 8 lb lime. The mix designs are given in Table 5.

Table 5. Mix Designs for Evaluation of Expanded Slag in Nursery Applications

Mix design	Ingredients by Volume, ft^3		
	Batch 1 (Control)	Batch 2 (Partial Slag)	Batch 3 (Total Slag)
Peat moss	8	-	16
Bark	9	9	9
Coconut fiber	-	8	4
Perlite	4	-	-
Vermiculite	4	4	-
Expanded Slag	-	**4**	**6**
Total volume, ft^3	27	25	35
Pots/yd^3	75-80	75-80	75-80
Comments			
Health/appearance	Excellent	Excellent	Poor
Growth rate	Good	Good	Poor
Pot weight	Low	Medium	High

Note: 4 lb/yd^3 fertilizer (14/14/14) and 8 lb/yd^3 lime were used for each batch.

Evaluation consisted of observation of the growth rate, general health, and appearance of fuchsia plants grown in a solarium. The performance of mix Batches 1 and 2 was identical in terms of plant growth rate, general health, and appearance. However, the mix for Batch 3 did not provide a good growing medium possibly due to its high water retention capacity. Also the slag made the pots unacceptably heavy for 12-inch hanging baskets. It was concluded that expanded slag can be used as a partial substitute for perlite and vermiculite. The following general comments and conclusions were made by the nursery:

- The Batch 3 mix design is not suitable for expanded slag and needs to be modified based on Batch 2.
- Since slag has a good water retention property, more attention needs to be paid to understanding its water release rate requirements.
- Because expanded slag is heavier than perlite and vermiculite, it may be more suitable for use in pots larger than 3 gallons in size and in large containers used for growing tall plants. Slag will help improve the stability of large pots and containers.

4.5 Evaluation of SLA in Production of Cement Panels (Waterproof Boards)

Based on evaluation of the results from the use of SLA in insulating concrete, another similar application was identified: lightweight cement concrete panels used in the construction of bathrooms and other areas where the walls are exposed to moisture. This is a relatively new but fast growing application that requires 35-40 lb/ft^3 aggregate. Praxis contacted a manufacturer and sent samples of SLA to them for laboratory evaluation. Based on these results, a large sample will be provided for the production of a large batch of panels. The size distribution of the SLA used for this application is given in Table 6.

Table 6. Size Distribution of SLA Used in Concrete Panel Application

Size	User Specification	Slag I (Drum 4)	Slag I (Drum 10)
+4M	0	0	0
4 x 8M	5-15	0.8	3.4
8 x 16M	25-35	55.3	61.8
16 x 30M	25-35	31.3	25.4
30 x 50M	5-15	11.3	8.6
50 x 100M	5-10	0.7	0.4
100M x 0	3-8	0.6	0.4
Unit weight, lb/ft^3	42-52	55.9	40.7
Moisture range, %	5-13	<1.0	<1.0

The initial comments from the manufacturer were that the SLA sample is of excellent quality from their viewpoint. Test work is in progress, and they have requested a larger (10 ft^3) sample to make a batch of concrete panels.

5.0 PLAN FOR THE NEXT QUARTER

The following activities are planned for the next quarter:

- Complete laboratory evaluation of expanded slag products for horticultural applications.
- Complete laboratory testing and select a mix design for the commercial-scale block-making production run.
- Complete laboratory evaluation of the slag lightweight aggregates for concrete panel applications.